31 Percutaneous Nephrolithotomy

Indications and Outcomes

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Key Words: Nephrolithiasis; kidney; percutaneous access; nephrolithotomy.

HISTORY

The management of renal calculus disease underwent drastic changes in the early 1980s with the arrival of percutaneous surgery and shockwave lithotripsy within several years of each other. Previously, patients were managed with an array of open procedures, including pyelolithomy, ureterolithotomy and anatrophic nephrolithotomy. The opportunity to effectively manage renal calculi in a percutaneous manner has drastically reduced patient morbidity when compared to an open, flank approach. Fernstrom and Johansson were the first to describe a percutaneous approach to the renal collecting system for the management of calculi *(1)*. Much of the early pioneering efforts were performed at the University of Minnesota and were made possible by the arrival of improved equipment and of an effective ultrasonic device that could be used to destroy and remove stones of varying compositions *(2)*. Although the availability of improved access devices, nephroscopes and lithotrites have made this procedure more facile and safe, the basic principles and techniques have not changed dramatically over the past 20 yr.

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Table 1
Indications for Percutaneous Nephrolithotomy

Strong
- Calculi >2–3cm
- Staghorn calculi
- Complex calculi (multiple calyces)

Possible
- >1 cm calcium oxalate monohydrate calculi
- >1 cm cystine calculi
- Calyceal diverticular calculi
- >1 cm lower pole calculi
- >1 cm renal calculi in patients with urinary diversions
- >1 cm renal transplant calculi
- Calculi associated with UPJ obstruction
- Large proximal ureteral calculi

INDICATIONS

Although significantly less morbid than open surgery, percutaneous nephrolithotomy (PCNL) is still the most invasive approach to urinary lithiasis when compared to ureteroscopy or extracorporeal shockwave lithotripsy (SWL). Consequently, this technique is generally reserved for specific needs (Table 1). Bulky stones greater than 2 cm are frequently best treated with a percutaneous approach to minimize repeat treatments and trauma to the kidney. Complete stone clearance can also avoid the risk of steinstrasse if the ureter is unable to accommodate a large bolus of stone debris. These concerns are especially true of staghorn calculi or complex stones that occupy multiple calyces. Some stones are simply too dense or organic in nature to respond well to SWL and may be best served with an initial percutaneous approach. Calcium oxalate monohydrate calculi are noted to be the densest stones and often experience incomplete fragmentation *(3,4)*.

Cystine stones are also resistant to shockwave energy, likely owing to their organic origin and their tight crystalline formation. Additionally, residual cystine fragments can easily act as "seed calculi" leaving the patient with multiple smaller stones rather than their initial large calculus. In light of these difficulties, many authors advocate a percutaneous approach for cystine stones even less than 2 cm in order to achieve complete stone clearance *(5,6)*.

Some stones smaller than 2 cm may be best treated with a percutaneous approach if they reside within difficult anatomic locations. Calyceal divertula have a tight neck that will not allow the easy passage of stone debris. If the diverticulum is inaccessible from a retrograde ureteroscopic approach, then percutaneous access can clear any stone material and allow either destruction of the urothelial lining or creation of a wider infundibular orifice (or both) *(7,8)*. Owing to obvious anatomic constraints, this technique is best reserved for posterior calyces.

Stones within a lower pole calyx may have a difficult time clearing out of this region into the pelvis and down the ureter following SWL. A well-controlled large randomized trial has demonstrated that percutaneous nephrolithotomy is superior to SWL for lower pole calculi *(9)*. The difference was particularly dramatic for stones larger than 1 cm.

Table 2
Contraindications for Percutaneous Nephrolithotomy

Absolute	*Relative*
• Uncontrolled coagulopathy	• Ectopic kidney
• Active urinary tract infection	• Fusion anomalies
	• Severe dysmorphism
	• Morbid obesity

Several authors have identified anatomic features of the lower pole collecting system that might allow for the easy clearance of fragments after SWL. These include the presence of an obtuse infundibular/renal pelvis angle (>70°), a short infundibular length (<3 cm) and a wide infundibular neck (>5 mm) *(10)*.

Patients with urinary diversions and moderate-to-large calculi may be best served with PCNL if retrograde access is too difficult or if the presence of infected stones and colonized urine preclude the use of shockwave lithotripsy. These patients fare well if they are covered with broad spectrum antibiotics and pre-placement of the percutaneous access 1–2 d before their procedure *(11)*.

Urinary lithiasis within a kidney transplant may require a percutaneous antegrade approach if the stone or the patient are not amenable to SWL. In addition, transplant ureters can be difficult to access in a retrograde fashion owing to angulation and narrowing at the uretero-vesical anastomosis.

The presence of co-existing pathology may also require a percutaneous approach. Patients with large calculi and a ureteroplevic junction obstruction (UPJO) may be best served by performing a PCNL and an antegrade endopyelotomy in the same sitting. Care must be taken to discern the difference between a primary UPJO causing stone or a stone causing a secondary UPJO.

CONTRAINDICATIONS

Several conditions can preclude the use of a percutaneous route to remove renal calculi (Table 2). An uncontrolled coagulopathy (either pathophysiologic or pharmacologic) puts the patient at too great of a risk for severe hemorrhage. Because each kidney receives 5–10% of the total cardiac output with each beat of the heart, uncontrolled hemorrhage can be rapid and require transfusion, selective arterial embolization or even nephrectomy. Significant amounts of irrigating fluids are absorbed during a PCNL owing to extravasation into the retroperitoneal space and the opening of venous sinuses within the renal parenchyma. The presence of an active urinary tract infection, therefore, places the patient at a greater risk of bacteremia of even septicemia with vascular collapse.

Renal anatomic abnormalities may make it difficult to adequately and safely access the collecting system. This includes renal ectopia (e.g., pelvic kidney) or fusion anomalies (e.g., horseshoe kidney). Although these anomalies are not absolute contraindications for the performance of a PCNL, good spatial orientation, excellent preoperative imaging and a very healthy respect for surrounding viscera and vasculature are crucial *(12)*. Patients with a solitary kidney should be approached with care. Any surgical intervention runs the risk of permanent injury to the sole functioning renal unit.

Fig. 1. Large, branched staghorn calculus completely filling the collecting system of a left kidney.

OUTCOMES

The technical success of percutaneous nephrolithotomy has made this technique the standard of care for many calculi and scenarios as outlined in the Indications section. A careful assessment of results, however, reveals that the expected outcomes and risks vary with the specific application.

Staghorn Calculi

Staghorn calculi (either partial or complete) represent a unique challenge for the endourologist (Fig. 1). The sheer bulk of the stone burden and the complex branched anatomy of the collecting system require careful planning regarding access and plurality of access tracts. Additionally, these calculi are typically associated with an infectious etiology. Antibiotics are never able to completely penetrate the interstices of a complex stone, running the risk of a release of bacteria and endotoxin during stone ablation *(13)*. Despite these warnings, however, PCNL remains the standard of care for staghorn calculi, replacing anatrophic nephrolithotomy and other open approaches.

Results from many authors have demonstrated the superiority of PCNL over SWL alone. In 1994, the evidence was compelling enough to prompt the AUA Guidelines Committee to recommend PCNL as first line therapy, often combined with SWL to ablate calculi in difficult to reach calyces *(14)*.

Second-look PCNL may also be added to the end of this regimen to "clean-up" any residual fragments left after the shockwave lithotripsy. This technique has been dubbed "sandwich therapy." Stone-free rates tend to range from 70 to 100% with this approach, with acceptable complication rates. Randomized trials have been performed comparing a combination of PCNL with SWL vs SWL alone. One particularly noteworthy analysis from Meretyk et al. demonstrated a stone-free rate of 74% with combination therapy vs 22% with SWL alone *(15)*. Nearly half of all shockwave lithotripsy patients had septic episodes whereas the combination patients had an 8% rate. Finally, 26% of the monotherapy patients required ancillary procedures over 6 mo vs 4% of the combination patients over one additional month.

Chandhoke has demonstrated that initial combination therapy is more cost effective than shockwave monotherapy *(16)*. This is especially notable when the stone surface area exceeds 500 mm^2 when measured in its greatest dimensions. This implies a calculus at least as large as 2.2 × 2.2 cm, clearly within the parameters of a typical staghorn calculus.

More recently, some centers have moved away from a sandwich technique, relying on aggressive PCNL at the first sitting. This may require the use of a supracostal access or a multi-tract access at the first procedure *(17–19)*. These same approaches may remove so much stone burden that there is no longer a need for the "meat" portion of the sandwich (SWL) or the second-look PCNL.

Others have moved away from the removal of all residual fragments, electing to treat small remnants with aggressive medical therapy *(20)*. This therapy should be directed by the information gained from a complete metabolic evaluation and/or stone analysis. Anatomic abnormalities (UPJ obstruction, caliceal diverticulum) or genetic predisposition (cystinuria) that played a role in the formation of the original calculus should be addressed if possible. Residual fragments should be small and expected to have a reasonable chance of spontaneous passage. The presence of infected fragments is generally frowned on as these can easily act as "seed" calculi and reinfect the patient's urinary tract.

Simultaneous Bilateral Percutaneous Nephrolithotomy

Several authors from various institutions and nations have described the performance of bilateral PCNL in one operative setting to avoid the costs and risks of multiple anesthetics *(21–24)*. All authors provide the caveat that the decision to proceed on to the second side is determined by the clinical result and the relative ease of performance of the first side. Significant hemorrhage, prolonged stone extraction time, multiple access tracts and instability of vital signs all warrant the cessation of surgery after completion of the initial side. The most symptomatic side is usually approached first. Alternatively, the renal unit most at risk of injury owing to obstruction or bulky stone burden may be treated initially. Two of the series compared bilateral PCNL patients to either unilateral PCNL or staged PCNL *(22,23)*. Both demonstrated increased transfusion requirements for the bilateral patients but noted that this was more closely related to number of nephrostomy tracts employed and the relative stone burden addressed. That is, smaller stone burdens addressed with one nephrostomy tract on each side appeared to lose as much blood as an equal stone burden on a unilateral patient treated via two nephrostomy tracts.

These same authors report that they are able to proceed on to bilateral PCNL in the majority of patients selected. Both Dushinski and Maheshwari reported that 94–96% of patients were able to be treated with a bilateral approach when surgically planned *(21, 24)*. However, none of the authors are able to identify how many patients were screened for a bilateral approach and deemed too risky for consideration of such an undertaking. Judicious patient screening, careful technique on the initial side, and sound intraoperative judgment are all crucial for the safe performance of a bilateral, synchronous nephrolithotomy.

Supracostal Access

As the kidney lies within the retroperitoneum, the lower pole is displaced ventrally and laterally by the body of the psoas muscle. As a result, the upper pole of the kidney

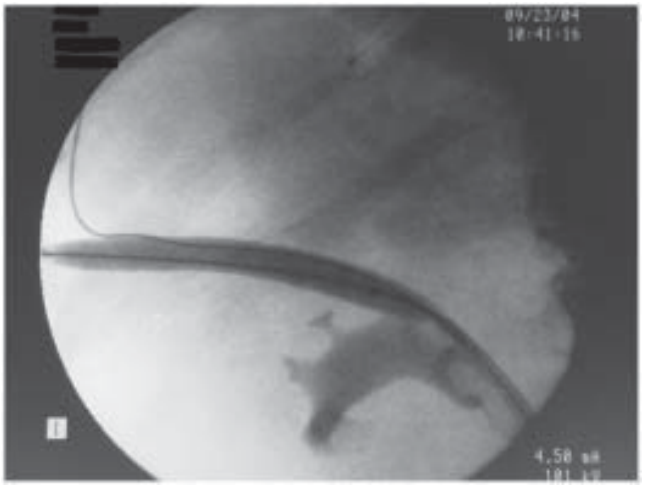

Fig. 2. Dilating balloon traversing percutaneous tract via puncture above the 12th rib. Calculi are visible as filling defects within the renal pelvis.

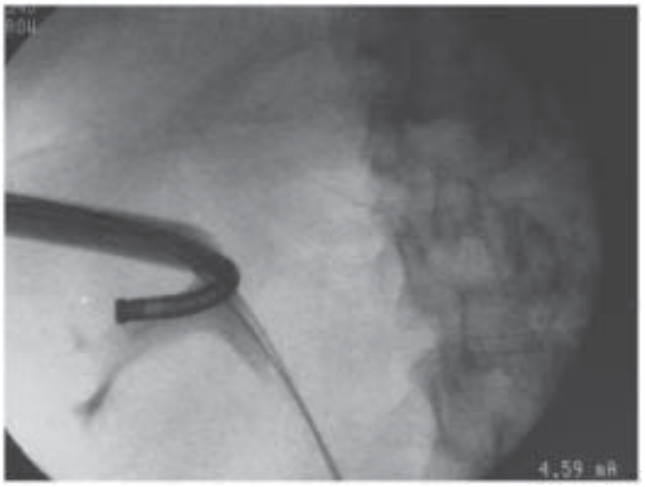

Fig. 3. A flexible cystoscope is introduced through the upper pole access and directed into an upper, lateral calyx to confirm complete stone clearance.

represents the most superficial access point during a posterior percutaneous approach. Entry into the lower pole can be hampered by the presence of adipose tissue and/or large buttocks. In addition, entry into the collection system sometimes requires unimpeded endoscopic access to the ureteropelvic junction or proximal ureter. For these reasons, some authors have advocated the use of an upper pole access during PCNL. Depending on the height of the kidney in the retroperitoneum, this may require that the tract gains entry above the 12th or even the 11th rib. This approach has been termed “supracostal” (Fig. 2). Although not without risk, this approach offers excellent visualization of the upper pole, the lower pole and the UPJ. The use of flexible nephroscopy also allows reasonable access into many (if not all) of the lateral calyces (Fig. 3).

Indeed, Wong and Leveillee have demonstrated that a primary upper pole access is effective for a series of staghorn and complex calculi that were all at least >5 cm in size *(17)*. By employing flexible endoscopes, a Holmium laser, nitinol baskets and second-look PCNL, the authors were able to able to render 95% of the patients stone-free. This did require an average of 1.6 procedures per patient. Complications were reasonable. They report a 2% transfusion rate, a 3% incidence of pneumothorax and 12% of the patients experiencing a postoperative febrile episode.

Gupta et al. reported a series of 62 patients who underwent supracostal access for PCNL. All tracts were above the 12th but below the 11th ribs *(25)*. With this approach, 90% of the patients were either stone-free or reduced to clinically insignificant fragments. The staghorn patients fared well with an 84% stone-free rate. Chest complications developed in 5% of the patients, all of which were managed with chest tube decompression. The authors conclude that fear of chest complications should not preclude the use of supracostal access if it is needed for adequate access. As expected, they also advocate the acquisition of an upright chest radiograph at the end of every supracostal PCNL.

Munver et al. have also outlined an extensive series of patients, reporting on the complication rates of 98 supracostal access tracts *(26)*. Seventy-two of these tracts were above the 12th rib, whereas 26 were above the 11th. Not surprisingly, the higher the access tract the greater the rate of complications. Seven patients (7%) had intrathoracic problems, all managed with chest tube drainage. Of note, the authors also compared the supracostal patients to a contemporary series of subcostal PCNL patients and noted only one intrathoracic event out of 202 subcostal tracts (0.5%).

Multiple Access Percutaneous Nephrolithotomy

Clustered or staghorn calculi may be too complex to completely reach with the rigid nephroscope through one single access tract. As noted previously, some remnant stones can be reached with a flexible nephroscope through one access (especially if it is through the upper pole). Alternately, some have advocated the placement of additional nephrostomy tracts to reach isolated calyces and bulky remnants *(27)*. Indeed, this tactic has been employed since the early development of the percutaneous technique *(28)*. Most authors report increases in transfusion rates as the number of tracts increase.

Tubeless PCNL/Reduced Drainage PCNL

Although percutaneous nephrolithotomy is clearly effective, there is no doubt that it creates significant discomfort. Many endourologists have tried various measures to reduce postoperative pain without sacrificing efficacy or safety. One approach involves the placement of a small drainage catheter at the end of the procedure. It is presumed that the reduced diameter of the nephrostomy tube can reduce pain after the operative procedure. Pietrow and colleagues randomized patients to standard 22 Fr catheter drainage vs 10 Fr drainage utilizing a small locking loop catheter *(29)*. Patients demonstrated significantly less pain in the immediate perioperative period if they had the smaller tube, although this advantage waned quickly and was no different at the 14 d postoperative follow-up. Importantly, there was no difference in complications or in hematocrit change between the two groups. Moreover, many of these patients were treated through a supracostal approach, which is generally considered more painful.

Others have also studied this modification. A recent investigation by Liatkos et al. randomized patients to receive either a standard 24 Fr Malecot re-entry catheter or an

18 Fr catheter with a tail-less stent following PCNL *(30)*. This study found that those patients with the smaller tube and the tail-less stent had less pain than the standard cohort. Of note, these authors did not assess the patients' perception of pain until their 2-wk postoperative visit. Although the patients appeared more comfortable, it is hard to distinguish whether this difference is caused by the smaller drainage catheter or to the presence of a tailless stent.

Bellman has promoted a tubeless technique in selected patients. In this approach, the full PCNL is performed in the usual fashion (*31,32)*. If the patient meets strict criteria, an internal ureteral stent is placed, the nephrostomy access tract is removed and the skin is closed. Patients must not require a second-look procedure and must therefore be rendered stone-free during their operation. Significant intraoperative hemorrhage, large stone volume, prolonged procedure times and a risk of infection have all been used as exclusion criteria for a tubeless procedure. Using these parameters, Bellman and colleagues have demonstrated decreased postoperative pain and decreased analgesic requirements from those treated in a standard fashion. They do not report any increase in complications nor in transfusion requirement. This technique has been duplicated by others with similar results, confirming its safety and efficacy.

The ability to apply this technique beyond these strict guidelines has been proposed and several have explored methods to close the tract to limit postprocedural hemorrhage. Noller and colleagues have employed fibrin glue to seal the access tract at the end of the procedure and have reported satisfactory results with small changes in hematocrit and no need for transfusion *(33)*.

Clayman and colleagues have used a novel hemostatic agent (Flo-Seal Matrix, Baxter Healthcare Corp., Deerfield, IL) to fill the access tract before removal of the final safety wire *(34)*. A ureteral occlusion balloon is placed at the edge of the calyx to keep the material next to the parenchyma and out of the collecting system. Both of these approaches may allow a wider application of the tubeless technique. All authors repeat the caveat that the procedure must be uncomplicated and that there must be no need for re-entry into the collecting system.

In an interesting prospective, randomized study, Desai et al. compared standard large bore drainage to small catheter drainage and a tubeless technique *(35)*. The patients met reasonable, but strict exclusion criteria that prevented an increased risk of complication from any of the methods. The authors found that patients in the tubeless group had the least postoperative analgesic requirement, followed by the small-bore catheter group. Additionally, these patients had the shortest duration of urine leak through the nephrostomy tract. As in earlier studies, there was no difference in transfusion requirements among the three groups.

Intracorporeal Lithotriptors

The performance of a successful percutaneous nephrolithotomy is dependent on the ability to gain safe access into the collecting system and on the ability to fragment and remove calculi once the stone has been encountered. The development of an effective handheld ultrasonic device has been crucial to the efficacy of this procedure. After its introduction in the early 1980s, it quickly became the instrument of choice owing to its ability to fragment calculi of all compositions. The hollow channel and continuous suction allow debris to be removed at the same time, thereby keeping the operative field free of fragments and clot. Although the ultrasonic device can address all stones, it can be slow and tedious when applied to very hard calculi such as calcium oxalate monohydrate.

Pneumatic devices have also been employed. These instruments use compressed nitrogen gas to drive a piston in the instrument, which subsequently fragments the calculi into increasingly smaller pieces. These pieces must be extracted with a grasper or with an ultrasonic device once the stone has been ablated. Although quite effective for stones of all densities, the time required to remove all the fragments can also be significant and tedious.

More recently, a combination device has been introduced that places a thin pneumatic probe within the central channel of an ultrasonic probe. Early studies from several investigators are promising and demonstrate faster operative times with no increase in complications. Pietrow et al. compared two cohorts of patients, one treated with the combination device and the second with an ultrasonic device alone *(36)*.

The combination instrument was able to treat all stones regardless of composition. Operations were quicker with the new instrument, with all gains coming from reduced fragmentation time. Hofman et al. have reported similar results, noting a decrease in disintegration time of 30–50% when applied to an in vitro model. The device was equally effective in a clinical setting, reducing operative times through the rapid disintegration of the target calculus *(37)*.

COMPLICATIONS

The list of potential complications from PCNL is long and varied. The percutaneous access must traverse multiple tissue layers and planes, including skin, subcutaneous fat, muscle, fascia, perirenal fat, and parenchyma. In addition, difficulties can arise from the location of the access tract, trauma to the renal parenchyma, injury to the collecting system, hemorrhage, fluid shifts or even the physiologic stress of surgery. Rarely, other structures may be abnormally displaced and are at risk of inadvertent damage. An incomplete list includes: colon, small bowel, spleen, liver, gallbladder, and the great vessels.

Transfusion rates generally run in the low single digits, but have been reported as high as 50% in some older series. Hemorrhage can arise from the parenchyma of the kidney, from branches of the renal vasculature or from the torn edges of the urothelium. As mentioned in previous sections, increasing the number of access tracts will increase the need for transfusion. A rare but impressive source of postoperative hemorrhage is from the formation of an arteriovenous fistula along the percutaneous tract (Fig. 4). These patients can present with massive hematuria and usually require embolization (Fig. 5) or even nephrectomy.

Urinary tract infection and sepsis are always a risk during this procedure owing to colonization of the urine and sequestration of bacteria within the calculi. Careful attention to preoperative urine cultures and the liberal use of perioperative antibiotics can minimize the risk of overwhelming infections. Patients with known or suspected struvite calculi should be treated with extra care. Rubenstein et al. have demonstrated that even patients with neurogenic bladders and known urine colonization can be safely treated with this technique *(11)*. These authors have advocated the placement of the nephrostomy access one day before the scheduled procedure to allow time for observation and the early treatment of signs of systemic infection.

Colonic perforation has been reported from multiple authors and sites *(38–40)*. This particular complication is thought to be caused by the presence of a retrorenal colon or caused by the placement of the access tract in too lateral a location. Very thin patients may be at higher risk, as are females and left-sided procedures. Surgeons may not notice the problem until after the case has been completed, because the nephrostomy access

Fig. 4. Angiogram demonstrating a large pseudoaneurysm in the right kidney. This patient presented 2 wk after uneventful PCNL with massive gross hematuria.

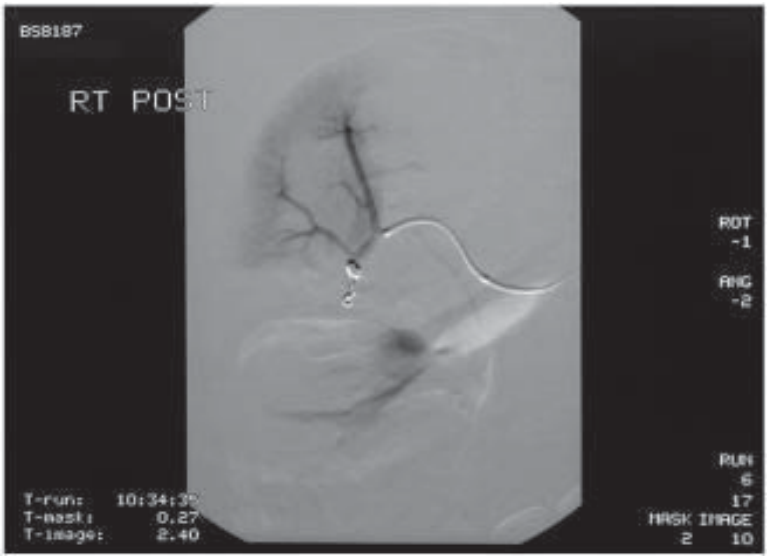

Fig. 5. Same patient after selective embolization of the pseudoaneurysm.

sheath will likely tamponade the defect and "bypass" the injury. Patients may develop significant fevers or abdominal pain in the postoperative period. Feculent material may be visible in the urine, the urine leak may cause watery diarrhea or stool may exude from the nephrostomy tract. Most authors recommend the placement of a ureteral catheter or stent to attempt to divert the urine down towards the bladder and away from the nephrocolonic fistula. In addition, the nephrostomy should be pulled back into the colon

to allow the fistula to heal spontaneously. Colon resection is always a distinct possibility but is usually avoided.

Intrathoracic complications can arise from upper pole or supracostal access tracts when the pleura are violated. Pneumothorax, hydrothorax, or hemothorax have been reported. Intraoperative manifestations may include difficulty with mechanical ventilation, poor oxygenation, hypotension or cardiovascular collapse. The fact that the patient is usually in a prone position for this procedure can make recognition and management of a severe intrathoracic complication quite challenging for the anesthesiologist. Most of these patients can be managed with the placement of a draining chest tube, which may be placed intraoperatively if the complication is recognized during the procedure *(41)*. Intraoperative fluoroscopy can be used to diagnose the condition with poor penetration of the ipsilateral lung field or for the correct interpretation of a collapsed lobe.

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32 Percutaneous Nephrolithotomy

Technical Aspects

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INTRODUCTION

In 1976, Fernstrom and Johansson reported the first successful percutaneous nephrolithotomy (PNL) in three patients *(1)*. Since then, advances in the design of nephroscopes and new methods to fragment large calculi have increased the safety and efficacy of this operation. PNL is an integral part of modern urological training *(2)* and is widely performed in both academic and community settings *(3)*. Recently, the American Urology Association (AUA) published its guidelines *(4)* regarding management

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of staghorn stones, and PNL holds a central position in the surgical approach for these cases.

In general, PNL can be considered a four-step operation: percutaneous renal access, tract dilation, stone fragmentation and extraction, and postextraction drainage. Each of the above steps requires meticulous attention to detail, and in cases where one method fails, an alternative maneuver may be required. PNL can thus be technically challenging, with potential for severe complications. In this chapter, we review the technical considerations for successful PNL.

PREOPERATIVE PREPARATION

The patient should be counseled of the potential risks and benefits of PNL, including the risks of injury to adjacent organs *(5–7)*, transfusion *(8)*, renal loss, and sepsis *(9)*. Minor complications have been reported in 11–25% of cases, whereas major complications occur in 1–7% of cases *(10)*. The only absolute contraindication to PNL is uncorrected coagulopathy. Patients should discontinue aspirin and nonsteroidal anti-inflammatory drugs 7–10 d before surgery.

Standard preparation includes a type and screen of the blood and culture-specific antibiotics in those with severe urinary tract infection. Although objective data are scant, prophylactic antibiotics in the form of first generation cephalosporin are given before percutaneous access and continued for 24 h following surgery. Bowel preparation is not routinely performed. Before surgery, the surgical team should ensure equipment availability that is in good working order. Although deep sedation has been used, general endotracheal anesthesia is preferred by most because this allows optimal airway control in the prone patient. Furthermore, in upper pole punctures, breath holds can be performed more precisely, allowing for increased safety.

POSITIONING

Following endotracheal intubation, the patient is placed on the operating table in a prone position. Ipsilateral ureteral catheterization can be performed before or after prone positioning. Most surgeons routinely place an angiographic exchange catheter and only rarely use an ureteral occlusion balloon. Prevention of neuromuscular injury associated with positioning is important and thus the surgeon should take an active role in patient positioning. The endotracheal tube, face, and cervical spine are protected. The shoulder and elbow joints are flexed to angles less than 90° and well-padded. The knees are flexed. Bolsters are placed longitudinally from the shoulder to the iliac crest, preventing undue pressure on the medially positioned breasts and male genitalia. The shoulders, hips, and legs are secured with heavy tape and any hindrance to movement of the fluoroscopy unit should be addressed. The back is prepped and draped. A commonly used drape is the neurosurgical craniotomy set with a fluid collection pouch and clear plastic adhesive at the surgical site. This protects the operating staff and room from the high volume of irrigant required during these procedures. It also helps maintain body temperature as patients frequently lose 2°C while positioning and preparing the patient before the incision.

There have been some reports of performing PNL in the supine *(11)* or lateral positions. Certainly, the supine position is preferable in the transplant kidney *(12)* and possibly the lateral position in a morbidly obese patient *(13)*. However, in the overwhelming majority of cases, the prone position is preferred.

Fig. 1. Severe bilateral nephrolithiasis. This patient required three separate punctures of the right kidney to clear the stone burden.

RENAL ACCESS

The importance of appropriate preoperative imaging cannot be understated when PNL is being considered in a patient with urolithiasis. CT has emerged as the preoperative study of choice owing to its high sensitivity and specificity *(14–16)* (Fig. 1). Although unenhanced CT is traditionally used for urolithiasis, contrast-enhanced CT's can be reformatted to demonstrate the stone and surrounding calyceal anatomy in a fashion similar to intravenous urography (IVU) *(17)*. Renal fusion defects or heterotopia (e.g., horseshoe kidney) *(18)*, perirenal anatomy (e.g., retrorenal colon, severe vertebral deformities) *(19)*, and extrarenal pathology can also be detected, and these may significantly impact the percutaneous surgical approach.

Although many urologists personally obtain renal access in the operating room ("single session" renal access and tract dilation), some prefer to obtain access preoperatively by the radiologist. The advantages of single session access are that it is more convenient for the patient as he or she is asleep during the entire procedure. Also, the urologist can pick the specific calyx and perform multiple punctures at his or her discretion. Furthermore, the urologist is not dependent on another specialty or the availability of the radiologist in scheduling the procedure. Potential disadvantages are that it may require additional training, longer operating room times, increased radiation exposure to the urologist, and technically difficult punctures may be easier to perform using the more versatile, advanced equipment typically found in the radiology suite *(20)*. The ability to choose the specific calyx to puncture is overwhelmingly the most important issue, and therefore, the single session PNL is preferred by the authors.

Fig. 2. Left calyceal diverticulum. Direct puncture into the diverticulum, with stone extraction and infundibulotomy performed.

After reviewing the preoperative studies, the surgeon decides on the optimal approach for stone extraction, while keeping in mind the potential limitations and complications of each approach. In general, lower and middle pole punctures are associated with fewer complications and preferred if complete stone eradication is possible via this approach *(21,22)*. Puncture into the fornix or papilla of a posterior calyx is ideally suited to minimize vascular injury and to assure direct access to the renal pelvis and indirect access to an anterior calyx. Infundibular and direct renal pelvis punctures are not recommended because vascular injury is more likely and can occur in up to 70% of cases.

Unless an anterior calyceal diverticular stone is being targeted (Fig. 2), anterior calyces should not be punctured because the majority of stone may be inaccessible using this approach. Furthermore, there is an increased risk of colonic injury and a tendency for severe torquing of the kidney using the rigid nephroscope that can crack the renal parenchyma and lead to increased hemorrhage.

Upper pole puncture is suitable if the majority of stone burden is located superiorly, if lower pole access could not clear all the stones, or if antegrade endopyelotomy is being considered as part of the procedure *(21,23,24)*. Pleural and pulmonary injuries are the main risks of upper pole puncture, but hepatic and splenic complications have been reported, and the surgeon should be cognizant of these potential issues *(10)*. Overall, hydropneumothorax has been reported to range between 9 and 37%, but in only 2–8% were they significant enough to require intervention *(25)*. Although needle aspiration of the hydropneumothorax is sufficient in most cases, larger collections may require tube thoracostomy drainage for 1 or 2 d *(26)*.

Multiple access is a technique to be considered when there is a large stone burden or if there are narrow, angulated infundibuli that cannot be addressed completely using a single access (Fig. 1). In such cases, maximal stone clearance is achieved using the first tract, then subsequent punctures are made targeting residual calcifications. If significant hemorrhage is encountered after the first puncture, the procedure should be concluded with a plan to return for a second stage.

Fluoroscopic Access

Both ultrasound (US) and fluoroscopy have been used to aid in the initial renal puncture, and this choice is dependent on surgeon preference and experience. In the fluoroscopic approach, dilute (1:1) iodinated contrast is instilled in a retrograde fashion through the previously placed externalized ureteral stent. The opacified calyces, stone/s, and their relationship to the overlying ribs allow the surgeon to target the appropriate calyx. Steady infusion pressure on the syringe during retrograde opacification can dilate the system, allowing a larger target for puncture. Overly zealous retrograde instillation can result in contrast extravasation and blur subsequent fluoroscopic images. Some instill dilute methylene blue with the contrast agent to help confirm entry into the collecting system.

On choosing a calyx, an 18-gauge or smaller Chiba needle is introduced under real-time fluoroscopy. Very small needles (<18 gauge) may not advance in a straight trajectory and thus are not routinely used by the authors. For lower pole punctures, a skin incision is made two finger breadths caudal to the 12th rib and two fingerbreadths lateral to the paraspinous border. The C-arm is placed such that the beam is directed in a anterior–posterior fashion. The needle is initially placed over the intended trajectory to the targeted calyx. The approximate angle for needle insertion depth can be approximated by aiming for the contralateral mid axillary line. The needle is then advanced in line with the target, and the depth can be fine tuned by rotating the C-arm towards the surgeon in a more horizontal orientation. If the tip of the needle is underneath the targeted stone then the trajectory should be steeper, and if the tip of the needle is above the targeted stone the trajectory should be more superficial. When all three axes are confirmed, the stylet is removed and the needle aspirated, demonstrating successful puncture. More commonly urine is not successfully aspirated and placing a J-tipped guidewire will confirm entry into the collecting system. In some cases, an air-contrast pyelogram is chosen as opposed to a contrast pyelogram, because air should outline the posterior calyces. Although this is theoretically an attractive method, the authors have found that it is not reliable.

Upper pole renal access on the other hand commonly requires a 12th rib supracostal approach. In this case, the C-arm's X-ray beam is oriented directly anterior–posterior, in line with the targeted upper pole calyx. The puncture site is frequently at the lateral edge of the paraspinous muscle. The skin incision is made, and the Chiba needle is advanced while keeping it exactly in line, parallel to the X-ray beam. The needle can be held with a ring forcep to reduce radiation exposure to the surgeon's hands. The biplanar C-arm is then rotated to a more horizontal orientation to confirm depth of the needle. Calyceal entry may be facilitated by small staccato advancements of the needle through the relatively tougher fasciae, renal capsule, and cortex. Entry is confirmed in a similar fashion to lower calyceal access.

If gross arterial blood or frank pus is expressed, the surgeon should consider placement of a nephrostomy, with a planned staged procedure. If the wire cannot be passed

across the ureteropelvic junction (UPJ) even with the help of an angled angiographic catheter, the wire should be coiled in the renal pelvis. Confirmation of entry into the collecting system is a prerequisite to tract dilation.

Sonographic Access

Interventional radiologists commonly use US to insert percutaneous nephrostomy tubes and similarly, many urologists rely on US for the initial needle puncture in PNL *(27)*. A potential downside of using US is that the collecting system may be nondistended. In fact, one of the benefits of retrograde opacification for fluoroscopic-guided renal puncture is that the collecting system can be dilated, making the target larger. Acoustic shadowing from calculi may hinder ultrasonic visualization of the collecting system. Acoustic shadowing also may be due to bowel gas and it is important to differentiate where the acoustic shadows are originating from.

Nevertheless, US is the modality of choice in select populations, such as in pediatric urolithiasis, pregnant patients and those with transplanted kidneys *(28,29)*.

In small children, retrograde ureteral access may be impossible, and US may be the only imaging modality that can be used for initial access. Once sonographically assisted renal access is established, routine fluoroscopy is preferable for tract dilation using antegrade pyelography. In the renal transplant patient, urolithiasis can present as acute anuria, graft tenderness, or recurrent infection *(12,28–31)*. The allograft's superficial location may simplify renal access, yet the severe peri-renal inflammation typically seen in such situations can make the dilation challenging. US is strongly recommended for the initial puncture owing to the potential for overlying bowel.

Although US is attractive because ionizing radiation is avoided, there are several important limitations. US is operator-dependent and although larger intrarenal stones and hydroureteronephrosis are visible, smaller stones and those in the ureter may be missed. Furthermore, US cannot differentiate nephrocalcinosis from nephrolithiasis.

In the sonographic approach, the US probe is first used to explore the entire kidney and the collecting system's orientation. Once the calyx of choice is identified, the probe is fixed while the 18-gauge Chiba needle is advanced. Hyperechoic needle tips can be seen entering the anechoic calyx, and entry can be confirmed with urine visualization after stylet removal or with appropriate guidewire advancement. A coaxial wire is then introduced into the collecting system to secure renal access. Antegrade pyelography opacifies the system to aid in tract dilation.

TRACT DILATION

Once initial wire access has been established, the tract must be dilated to allow placement of a safety wire. A 12-Fr fascial dilator is used to dilate the tract to accommodate a safety wire introducer. Thin 6- or 8-Fr fascial dilators may kink while attempting to advance over the initial guidewire. Some centers insist on always passing the safety wire through the UPJ and coiling it inside the bladder. Others routinely coil the wire inside the renal collecting system, and found that crossing the UPJ is neither mandatory nor advantageous, and needlessly increases radiation exposure.

Once both wires are secured, the working wire is used to dilate the tract. There are a variety of methods available, including balloon dilation *(32)*, Alken telescoping dilators *(33)*, and semirigid Amplatz dilators *(34)*. Balloon dilation has been demonstrated to be quick and safe, but more expensive *(35)*. Facility with alternate means of dilation is

prudent, because balloon dilation may be impossible in reoperative cases *(36)*. Another useful adjunct is the fascial incising blade that can be advanced coaxially over the working wire to incise the obstructing fascia (Cook Urological, Spencer, IN), in cases with significant perirenal fibrosis.

Several points of technique are worth mentioning here, to ensure safety and success. First, the vector force used to advance the dilator should be in the same direction as the introduced wires. Second, the radio-opaque tip of the dilator should be advanced just millimeters beyond the tip of the fornix, as deeper advancement can crack the infundibulum resulting in significant hemorrhage. Third, if the working wire does not move easily back and forth a few millimeters while advancing the dilator, the wire may be kinked, and the appropriate vector force may thus be inaccurate and the dilator may not follow the wire into the collecting system. Instead, the dilator may take a "false passage" into perirenal tissues.

After tract dilation, the working Amplatz sheath is advanced into the collecting system. In some institutions, a working sheath is not placed at all, and the rigid nephroscope is placed directly into the collecting system through the dilated tract. Although this closed sheathless system keeps the tract smaller and allows better hydrodistension of the collecting system, concerns for systemic absorption of irrigant and loss of renal access have led the authors to routinely use an Amplatz sheath. Furthermore, in the supracostal approach, inadvertent pleural injury and sheathless PNL may lead to massive hydropneumothorax.

Usually, a 30-Fr Amplatz sheath is used to accept a 26-Fr nephroscope, but there have been reports of successful mini-perc PNL using smaller Amplatz sheaths. In one extreme case, a 13-Fr ureteral access sheath was used *(37)* to decrease the morbidity for the patient. Many surgeons routinely use a 30-Fr sheath without problems. The smaller sheaths are useful in small pediatric patients.

Once the sheath is in place, the fluoroscopic arm should be moved out of the field, the nephroscope prepared, and lithotripsy probe readied. The irrigant of choice at this juncture is normal saline, because systemic absorption of dilute solutions may cause hyponatremia.

STONE FRAGMENTATION AND EXTRACTION

On initial insertion of the rigid nephroscope, vision may be obscured by blood clots in the sheath. They can be removed using suction and intermittent activation of the ultrasonic lithotripter. By following the guidewire in the sheath, the leading edge of the stone is usually found. If the collecting system is difficult to find, most commonly looking at the 12 o'clock position will help locate the collecting system. At this point, retrograde instillation of dilute methylene blue may aid in finding the collecting system. If the stone is less than 1 cm in size, a grasper can be used to remove it through the 30-Fr sheath. However, most stones requiring PNL will be larger than 1cm, and a variety of lithotripsy techniques will be required.

Ultrasonic Lithotripsy

Ultrasonic energy is the most commonly used method for intracorporeal lithotripsy owing to its demonstrated safety and efficacy *(38)*. The piezoelectric effect creates vibrational ultrasonic energy which is transmitted down the shaft of the probe *(39)*. These probes are always rigid, therefore rigid nephroscopy is required and its use is

limited to calyces which can only be safely reached without undue torquing of the kidney. Although solid probes are available, hollow ultrasonic probes are preferred because of the ability to suction simultaneously. They range from 3 to 12 Fr in size, with the hollow designs being larger in diameter.

Under direct vision, the surgeon gently presses the tip of the probe against the stone. As the surgeon activates the probe, the assistant or activation pedal modulates the suction, thereby balancing visibility by hydrodistending the system with evacuation of broken fragments. Stone graspers are used intermittently to remove fragments less than 1 cm.

Lithoclast

Another major energy source is the pneumatic lithotrite, or Swiss Lithoclast *(40)*. This device has a generator, hand piece, and foot pedal. When activated, compressed air propels a metal projectile inside the hand piece into the base of the probe. Pressures of up to 3 atm are generated, and this ballistic energy is transmitted along the probe onto the stone. No heat is generated, a potential advantage over ultrasonic energy.

Although this technology required rigid probes in the past, flexible probes are available in modern pneumatic lithotrites. Another advance is the merging of ultrasonic and pneumatic capabilities into a single probe, which may significantly decrease PNL operative times *(41)*.

On rare occasions, ultrasonic lithotripsy will be unable to fragment very hard stones, such as cystine, calcium oxalate monohydrate or brushite stones. More frequently, the ultrasonic lithotripter is out of order, requiring the surgeon to turn to other sources of energy. Furthermore, there is consensus that antegrade pyeloscopy should be performed in every PNL to ensure complete stone clearance. For these reasons, electrohydraulic lithotripsy (EHL) or Holmium:YAG laser *(24)* should be available for use.

Electrohydraulic Lithotripsy and Holmium:YAG laser

EHL probes range from 2 to 10 Fr in size, and a spark is generated between the insulated metal cores of the probe *(42)*. Heat generated by this spark causes fluid vaporization, formation of a cavitation bubble and creation of a hydraulic shock-wave.

The Holmium:YAG laser generates a beam with a wavelength of 2100 nm and pulse duration of 250 μs. This wavelength is highly absorbed by water, thus the laser fiber must be placed directly on the stone. Fibers range in size from 200 to 1000 microns, and the power generated by the machine is controlled by modulating the energy (Joules) and frequency (Hertz) of each pulse.

The benefits of using EHL or Holmium laser are that very hard stones can be broken, and that flexible nephroscopy can be used with these energy sources. However, a significant downside compared to ultrasonic lithotrites is that suctioning cannot be performed simultaneously. However, one recent report used an innovative suctioning device together with the Holmium laser *(43)*.

Flexible Nephroscopy

It is widely accepted that flexible nephroscopy should be performed before concluding PNL because only the most rudimentary collecting systems can be completely inspected with rigid scopes. Certainly, flexible nephroscopy is required during a second look, and EHL or laser fibers will allow fragmentation if residual stones are seen. Smaller fragments may be removed using baskets or flexible graspers.

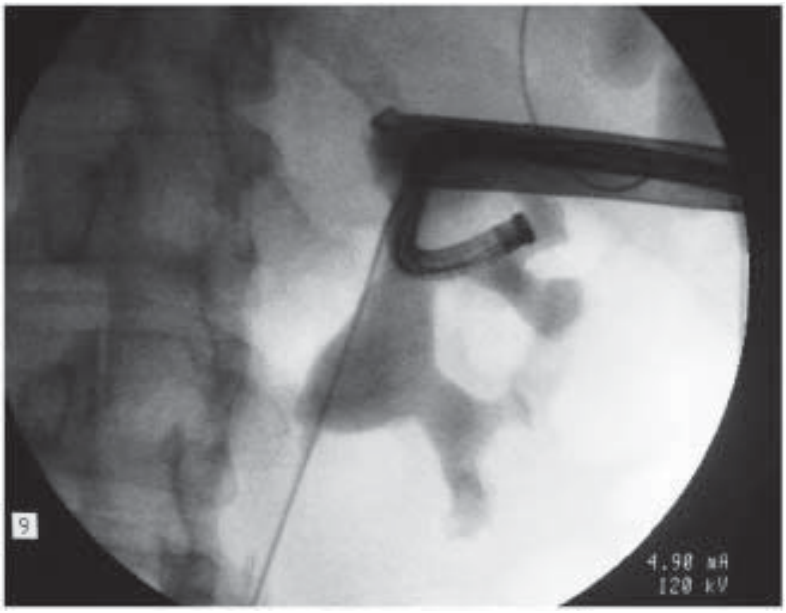

Fig. 3. Intraoperative flexible nephroscopy through a supracostal puncture. Antegrade contrast injection opacifies all the calyces to be examined.

Nephroscopy is performed using a conventional 14-Fr flexible cystoscope. Fluoroscopy will demonstrate suspicious areas of calcification within the renal shadow, and the surgeon should aim to inspect all such areas. Intermittently, contrast is infused through the scope to outline the calyceal anatomy and to convince the surgeon that all calyces have been thoroughly examined (Fig. 3). The proximal ureter should also be examined for residual fragments, and antegrade contrast infused into the ureter should demonstrate free flow into the bladder.

DRAINAGE AFTER PERCUTANEOUS NEPHROLITHOTOMY

Traditionally, a nephrostomy tube is placed at the conclusion of every PNL *(44)*. This allows maximal drainage of the kidney, maintains renal access if second look nephroscopy is required, and tamponades any bleeding points. However, some investigators have tested the feasibility of tubeless PNL in well-selected cases *(45,46)*. Candidates for this approach include patients in whom there is minimal intraoperative bleeding, and patients with a small stone burden and thus requiring minimal manipulation. Nonetheless, the authors routinely use nephrostomy drainage after all PNLs, and therefore drainage options are presented here.

There are myriad choices in nephrostomy drainage, and the final choice is dictated by surgeon experience and discretion. Self-retaining tubes (balloon-Foley, Malecot, Cope loop) are preferred over simple, nonself-retaining tubes such as red rubber Robinson catheters or modified chest tubes because the latter can be easily dislodged. Patient discomfort is greatest with large supracostal nephrostomy drainage tubes. If bleeding is of minimal concern, a 10–12 Fr Cope loop placed through a lower pole puncture will likely be most comfortable.

If second-look nephroscopy is planned for substantial residual stone burden, a nephroureteral catheter is prudent for easy, rapid access *(44,47,48)*. One option is to place a Malecot re-entry catheter, consisting of a Malecot tube with a filiform-like ureteral stent extending from its tip. The Malecot wings are positioned in the renal pelvis whereas the filiform-like ureteral stent traverses the UPJ and rests in the midureter. Another option is to place an antegrade single-J, 7 Fr ureteral stent or a routine 5 Fr angiographic exchange catheter to the bladder. Over these tubes, a 20 Fr Council tip catheter is positioned in the renal pelvis for maximal urinary drainage and secure renal access.

When multiple punctures have been performed, many frequently place a nephroureteral stent across the UPJ and into the bladder for maximal drainage. Alternatively, for the two tracts which have been dilated, an angiographic catheter can be placed from one to the other. Then, two self-retaining nephrostomy tubes can be placed coaxially from either end of this angiographic, creating a U-loop configuration. In cases of significant bleeding postoperatively, the Kaye tamponade nephrostomy *(49)* is an option before pursuing angiographic embolization. Most hemorrhage however can be controlled with clamping the nephrostomy tube/s for a short period postoperatively. Rarely, if bleeding is noted around the clamped tubes angiographic studies should be undertaken.

Twelve to 48 h after the percutaneous procedure, antegrade nephrostograms are typically performed. Complete scout radiographs should be performed to exclude residual stone fragments. Contrast should delineate upper tract anatomy and drain freely into the bladder. Hopefully there are no stones noted and there is free drainage into the bladder. In these situations the nephrostomy may be clamped and removed after a few hours or removed immediately after the study. If there are fragments large enough to be of clinical concern, the surgeon has the option of recommending shock-wave lithotripsy or second-look nephroscopy *(50)*.

Second-look nephroscopy has been performed under sedation, but the authors prefer light general anesthetic owing to airway concerns and the need for patient immobility. Some investigators perform routine postoperative abdominal CT, and this gives them an idea of the size and location of any residual fragments *(50–52)*. Laser lithotripsy and basket extraction is possible using a flexible scope passed through the previously dilated tract.

In this procedure, the patient is positioned in a prone fashion and a safety wire is placed under fluoroscopy. All stents and nephrostomy tubes are then removed, allowing a flexible cystoscope to be passed alongside the wire through a relatively well established tract. In cases of multiple residual fragments or in supracostal punctures, a small Amplatz sheath can be placed into the tract to prevent significant fluid extravasation. If a short second-look is expected in a lower pole puncture, a sheathless approach with a safety wire is sufficient.

COMPLICATIONS OF PERCUTANEOUS NEPHROLITHOTOMY

Bleeding, sepsis, and injury to adjacent structures are the most common and dreaded complications of PNL. Each complication has risk factors associated with it. For example, bleeding may be more likely after multiple punctures or larger stone burdens. Sepsis is more likely if active infection is present; adjacent organs may be injured depending on the percutaneous approach chosen.

Patients should be informed that contemporary published transfusion rates range from 1 to 10% *(8,53)*. Although conservative measures such as bed rest and hydration are the

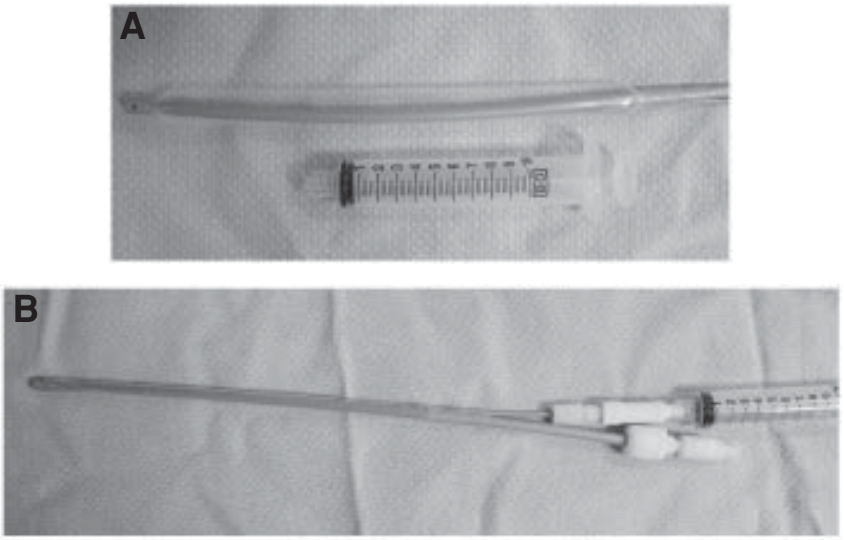

Fig. 4. (A) The Kaye tamponade nephrostomy tube can be inflated for compression of the nephrostomy tract in cases of severe hemorrhage. **(B)** Dual lumen of Kaye tamponade nephrostomy, allowing placement under wire guidance, antegrade nephrostograms, and hemostatic compression of nephrostomy tract.

first line of therapy for hemorrhage, patients should be informed of the possible need for angiographic embolization *(53)* and in extremely rare instances, renal exploration. Open exploration is the therapy of last resort as this typically results in partial or total nephrectomy.

Significant bleeding can manifest intraoperatively or postoperatively. During initial access, common mistakes are poorly targeted punctures or over-advancement of the dilator/s. These maneuvers may injure the infundibulum or cause frank perforation, resulting in excessive bleeding. If significant bleeding persists during lithotripsy, the surgeon should consider aborting the procedure, placing a self-retaining balloon-type nephrostomy, and returning to the operating room another day. If hemorrhage continues, the first step is to clamp the nephrostomy tube and allow the collecting system to tamponade for a few hours. A specially-designed "Kaye" nephrostomy tamponade catheter may be used for more brisk bleeding *(49)* (Fig. 4). More commonly, however, the dilation balloon and working Amplatz sheath tamponade these vessels allowing completion of the procedure. In unusual cases, brisk bleeding can recur at the conclusion of the procedure, once the tamponading effect of the Amplatz sheath is lost. In this situation, bed rest, transfusion and self-retaining clamped nephrostomy drainage typically control the hemorrhage.

Postoperatively, bleeding can occur on removal of nephrostomy tube or several days to months later after patient discharge. Bleeding that occurs at the time of nephrostomy tube removal requires immediate tube re-insertion, and consideration of angiographic embolization. Delayed hemorrhage typically presents as sudden gross hematuria, which requires immediate readmission to the hospital. Initial management consists of conservative measures such as bed rest and transfusion if necessary. Renal angiography is required to rule out a pseudoaneurysm or arteriovenous fistula. If this fails, embolization may be necessary for delayed arterial bleeding or possibly arteriovenous fistula.

Sepsis has been reported in up to 3% of PNL cases *(54,55)*. Sepsis may be minimized by instituting culture-specific antibiotics 1–2 wk before PNL. Perioperative intravenous antibiotics should be continued in those with renal infection, and intra-renal urine should be sent for culture during PNL if the surgeon suspects persistent urinary infection. This is an active area of research, and recent data have shown that intrarenal cultures can differ significantly from routine midstream voided cultures *(56)*. In the postoperative period, blood cultures, broad-spectrum antibiotics, critical care support including vigorous intravenous hydration, and maximal drainage with nephrostomy and/or ureteral stents are paramount if sepsis occurs.

Reported injury to an adjacent organ occurs rarely, between 1 and 4% of cases *(5,7, 26,57–60)*. Intraperitoneal extravasation can occur and may lead to physiologically significant intra-abdominal compression. Paracentesis or exploratory laparotomy may be required. In right sided PNLs, liver injury can occur whereas splenic injury has been reported during left sided PNLs. This can be dramatically reduced by studying preoperative CT scans. Conservative therapy is usually sufficient, although exploration has been reportedly necessary in some cases.

Supracostal puncture is being used more frequently. This has up to a 37% risk of pleural injury, with supra 11th rib approaches being associated with a significantly higher risk. The incidence of hydropneumothorax after PNL was studied by Ogan et al. in 89 consecutive patients *(25)*. In this study, 58% underwent supracostal puncture, and seven patients required intervention for hydropneumothorax. Two cases of hydropneumothorax were discovered during intraoperative chest fluoroscopy, and four by symptoms alone. In their institution, unenhanced abdominal CT was routinely obtained on postoperative day 1, and intervention was instituted in one individual with a significant effusion seen at the lung base. Furthermore, in no case was intervention made on the basis of immediate postoperative chest X-ray if intraoperative fluoroscopic images were negative. The authors concluded that routine postoperative chest radiography was neither necessary nor cost-effective in patients who had routine intraoperative chest fluoroscopy. In general, management is driven by patient evaluation. If the patient is stable, observation alone typically results in spontaneous resolution. Alternatively, one-time aspiration may be adequate whereas in more severe cases, a tube thoracostomy may be required for a few days.

PERCUTANEOUS NEPHROLITHOTOMY IN PATIENTS WITH DYSMORPHIC BODIES

Another common scenario for urologists is the neurologically deficient patient with scoliosis (Fig. 5) or body contractures. In these patients, there may be significant distortions to the bony and skin landmarks usually used for percutaneous access. Therefore, prevention of injury to adjacent solid or hollow viscera becomes an important consideration. Assimos and colleagues published a recent paper demonstrating the utility of CT guided renal access in the radiology suite *(19)*. In their multi-institutional study, six patients underwent successful PNL using this approach for patients with recognized spina bifida and retrorenal colon (Fig. 6).

Once access has been successfully obtained, PNL has been shown to be as effective and as safe *(61,62)* as PNL in patients without spinal cord issues. However, some special precautions are necessary, including the increased risk of infected renal units *(63)* and possibility of autonomic hyperreflexia *(64)*.

Fig. 5. Right renal nephrolithiasis in a patient with severe lumbar kyphoscoliosis.

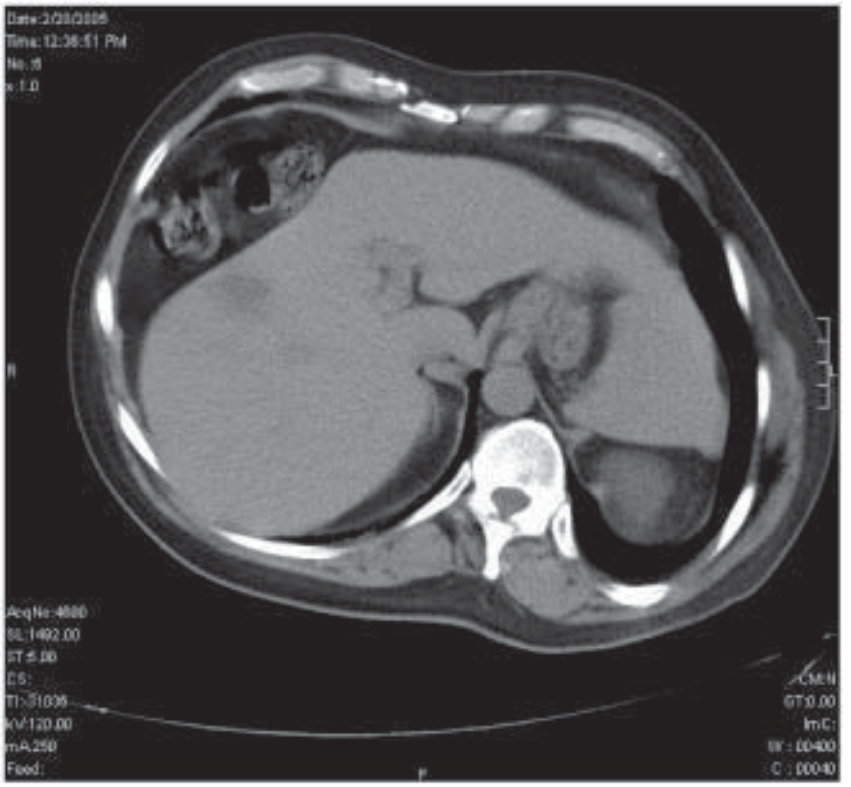

Fig. 6. CT scan of adult patient with myelomeningocele. Note the dysmorphia of the left abdominal cavity and significant pleura overlying the upper pole of the left kidney.

PERCUTANEOUS NEPHROLITHOTOMY IN THE TRANSPLANTED KIDNEY

Stones in renal allografts or autografts are rare *(30)* but mandate early aggressive treatment because these are solitary renal units *(31)*. Shock-wave lithotripsy has been used for small stones, but the urologist should strongly consider PNL to render the kidney stone-free *(28,29)*. A close working relationship with the transplant nephrologists is wise to monitor immunosuppression and infectious complications in these potentially complex patients.

Percutaneous access to transplanted kidneys is not extremely complex, because of its anterior position *(12)*. The authors favor an US-guided renal access to ensure a tract free of bowel loops *(29)*. Once needle access is obtained, antegrade opacification allows PNL to be completed in the standard fashion *(12)*.

PERCUTANEOUS NEPHROLITHOTOMY IN THE MORBIDLY OBESE

As morbid obesity becomes more prevalent in the United States, this may have an impact on the incidence of stones. The "metabolic syndrome" of obesity, systolic hypertension and glucose intolerance has recently been linked to urolithiasis *(65)*. In addition, whereas older studies have shown a 3 to 1 male to female predominance, recent updates demonstrate strong trends towards equalization of these rates. Investigators have hypothesized that the increasing obesity rate in women explains this trend.

Thus, urologists are frequently confronted with the difficult scenario of managing a large stone in the significantly obese patient. Shock-wave lithotripsy may be impossible in these cases owing to poor visualization on fluoroscopy, or the stone may be beyond the F_2 focal point *(66)*. Ureteroscopy is an alternative, but complications rise and stone-free rates drop dramatically as stone dimensions increase. PNL may be the most effective means to render the patient stone free, albeit at the cost of higher anxiety for the surgical team. Despite the increased complexity of PNL in the obese, studies have shown no difference in overall success and morbidity compared with nonobese patients *(67–69)*. Indeed, one study stratified PNL outcome by body mass index *(68)*, ranging from <25, 25–30, 30–40, and >40 kg/m^2 and found no differences in outcome. This was not likely to be a result of low statistical power, because success rates were remarkably similar, ranging from 76 to 83%.

Special anesthetic and surgical technical considerations have to be made when planning PNL in the obese. The CT scan should be used to measure the distance from the skin to the stone to determine if longer instruments will be required. Prone positioning can impair ventilation and crush injuries such as rhabdomyolysis have been reported. More than one operating table may be required to support the patient *(68)*, and the surgeon may need to work around poorer fluoroscopic images, inadequately short puncture needles and difficult tract dilation. Others have successfully used the flank position, which may result in less ventilatory compromise *(70)* and movement of the pannus away from the posterior abdominal wall. In the very obese with a very thick pannus, Curtis et al. *(71)* introduced a special method whereby a larger skin incision is made, followed by dissection down to the fascia. Once the fascia is encountered, the puncture needle is introduced at that level to access the kidney. Tract dilation can then be performed in the conventional fashion, but stay sutures should be placed on the outer end of the sheath to prevent it from advancing in the subcutaneous fat.

Manufacturers now offer longer sheaths and nephroscopes for PNL in the obese. Nevertheless, available instrumentation may still be inadequate in super-obese individuals. In such extreme cases, placing a percutaneous nephrostomy may passively dilate the tract allowing flexible nephroscopy at a second stage *(72)*.

CONCLUSIONS

PNL is an important surgical procedure for urologists caring for patients with nephrolithiasis. Successful stone eradication and patient safety are the most important goals, and this begins with proper patient selection, preoperative imaging and a skilled surgeon. It is critical that the surgeon is knowledgeable about various technical options at each step of PNL, and the potential pitfalls of this operation.

When performed on a regular basis, PNL is a versatile operation that can be used for staghorns, calyceal diverticula, transplant urolithiasis, and in special populations such as the obese or elderly.

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